Approved August, 1924.

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THE SOURCE OF THE WATER ALONG THE BALCONES FAULT ESCARPMENT

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THESIS

Presented to the Faculty of the Graduate School of
The University of Texas in Partial Fulfillment of the Requirements

For the Degree of

MASTER OF ARTS

By

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Maysfield, Texas

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PREFACE

The subject of this paper was suggested to the writer by Dr. H. P. Bybee, who has continuously interested himself in the completion of the work. The writer, however, is deeply appreciative of the timely suggestions, valuable data, and constant willingness of Professor F. L. Whitney to aid him in the preparation of the work. Dr. F. W. Simonds and Dr. E. P. Schoch also furnished suggestions and data which helped the author. Assistance in determining the analyses of various water samples was rendered by the Division of Industrial Chemistry, Bureau of Economic Geology and Technology. Professor F. L. Whitney, Mr. W. A. Maley and Mr. E. A. Wendlandt kindly aided in the preparation of the maps.

Austin, Texas

August, 1924.

CONTENTS

CHAPTER I

CHAPTER IV

THE SOURCE OF THE WATER ALONG THE BALCONES FAULT ESCARPMENT

CHAPTER I

Introduction

The area which demands consideration in this problem is in the south central part of the state, embracing all or parts of the following counties: Llano, Burnet, Williamson, Gillespie, Blanco, Travis, Kendall, Comal, Hays and Bexar.

With respect to the major physiographic divisions, the area above has the following limitations: On the south it is bounded by the Gulf Coastal Plain, and the southeastern portion of the province is a part of this division.

On the north the Grand Prairie touches the area in Travis, Williamson, and Burnet Counties. The Central Mineral region extends into Burnet, Blanco, Llano, Gillespie, and Mason Counties.

On the northwest the Edwards Plateau, a minor division of the Great Plains, extends into Gillespie, Kendall, Blanco, Travis, Hays, Comal, and Bexar Counties.

In central and southern Texas the line dividing the Great Plains and the Gulf Coastal Plain is a pronounced south-east to south facing escarpment produced by faults and dips and known as the Balcones Escarpment. This escarpment, coming into the state near Del Rio on the Rio Grande River, continues east to Medina County and there turns to the northeast. It passes through Bexar County in a direction approximating north 60 degrees east.

turns in Comal and Hays Counties and has an approximate direction of north 30 degrees east in Travis County.

The series of sub-parallel faults has produced a narrow belt of country occurring in Travis and through other counties to the southwest, the surface of which is composed of the outcrop of the Edwards Plateau. This area usually lies between parallel faults. Its type is splendidly developed between Manchaca and Oak Hill, Travis County. The surface is rough, broken and of a rocky character, covered with dense growth of junipers and scrubby oaks called hardscrabble.

This block of Edwards limestone varies from four to fifteen miles in width and ends at the western edge of Bexar County.

Topography and Drainage

The topographic and physiographic divisions in this group of counties are determined very largely by the geologic structure. The formations dip in general to the southeast. This also is the direction of the average maximum surface slope, but as the rate of dip of the formations is more rapid than the surface slope, it follows that in passing to the southeast younger formations come successively into the section. Each formation develops in the line of its outcrop a more or less well defined surface topography which is often very characteristic for that particular formation. The formations, containing much hard rock, resist decay and stand out as hills, often forming northwest facing escarpments. The softer and less resistant formations, on the other hand, produce either valleys or plains. The strike of the formations, as already indicated, is in general northeast--southwest. Accordingly, the topographic areas developed from these formations trend in a northeast--southwest direction across the country. In addition to topographic divisions dependent upon the surface outcrops of the formations, there is in these several counties a large development of flood plain deposits. These plains and terraces cut across and cover over the successive formations, concealing the surface features that otherwise would have characterized the outcropping of the underlying rocks.

The surface drainage of this area is to the south or southeast in the direction of average surface slope. The maximum elevation of the area is 1502 ft. north of Burnet, while near the southern part in Travis County the elevation is 400 ft. The principal streams of the region are South Fork of the San Gabriel River, Cow Creek, Sandy Creek, Barton Creek, Colorado River, Pedernales River, Blanco River, Guadalupe River, Cibolo River, Salado Creek and San Antonio River.

In places the waters of these rivers make wide and deep pools having the peculiar light sea-green color, characteristic of all spring-fed rivers breaking from the Cretaceous limestones of Texas. Because these rivers, flowing over the Edwards Plateau, constitute a group of streams characteristic of a large region in Texas, they have an important bearing on the question of underground water.

Climate and Rainfall

The extreme southwest portion of the area is intermediate in location between the arid southwest and the considerably more moist climate of the coastal plain and plateau region. The mean annual temperature at San Antonio, according to reports from U. S. Weather Bureau, is 68 degrees F. with 106 degrees F. as a maximum and 4 degrees F. as a minimum range of temperature. The mean annual temperature at Austin is 67.5 degrees F.

An idea of the annual rainfall may be obtained from the following chart made up from the data secured from the U. S. Weather Bureau, Texas Climatological Report:

Station Reporting	Rainfall in inches for: 1917	1918	1919	1920	1921	1922
Austin	18.58	27.92	64.68	37.68	51.73	37.32
Blanco	17.57	29.07	54.76	30.50	28.67	22.51
Boerne	20.82	30.58	64.70	27.99	32.81	26.23
Llano	10.16	27.77	47.88	30.76	18.77	28.50
New Braunfels	13.29	25.62	59.20	25.89	35.44	30.40
San Antonio	10.11	29.91	50.28	20.81	28.53	23.59
San Marcos	16.47	29.61	45.75	31.74	46.29	28.26
Uvalde	11.31	19.38	38.40	16.74	19.55	20.90
Kerrville	12.33	28.14	57.56	21.63	25.17	26.18

Balcones Escarpment

The Balcones fault is the leading structural feature of Central Texas. The different rock formations for many miles on both sides of the fault trend in long belts parallel to the line of faulting and dip in a direction at right angles to that line. North of Austin the fault runs in a direction slightly east of north; between Austin and San Antonio it gradually swings from a north-south to an east-west direction and continues in that latter direction from San Antonio to Del Rio. It is the frayed and coastward border of the Edwards Plateau. From the more open, level, lower country the escarpment appears as a sharp line of timber-covered hills and these are called mountains by the people of the region. In the area under consideration, the scarp commences near the northern boundary of Travis County and continues a little south of west through Travis, Hays, Comal, Bexar, Medina, Uvalde, Kinney to Val Verde County where it meets the Rio Grande. Near Austin its highest summits are 400 ft. above the margin of the lower plain. In Uvalde County, the summits are 1400 ft. above the margin of the lower plains.

CHAPTER II

Stratigraphic Geology

Even though the stratigraphic geology of the Central Mineral Region is not a matter of importance in the scope of this paper, it should be mentioned because the rocks outcrop to the north of the catchment area of the Trinity sands.

The Central Mineral Region is a basin-shaped depression which the Colorado and its tributaries have stripped of its former cover of Comanchean rocks. In this region outcrop pre-Cambrian, Cambrian, Ordovician and Pennslyvanian rocks. Although its surface is considerably rougher than that of the adjoining Edwards Plateau, it is, in reality, a low plains country. The lowest part of the Central Mineral Region is the area of outcrop of the pre-Cambrian rocks. Above the pre-Cambrian rocks, the Cambrian, Ordovician, and Pennsylvanian rise in escarpments to broad flattened surfaces. Then follows the rim of Cretaceous rocks which, of course, have a direct bearing on the source of underground water.

The Mesozoic Sediments

The Travis Peak beds are the lowest Cretaceous formations exposed in this region. They outcrop in quite a large area extending from Burnet south to Volente in the Colorado valley, along the Pedernales River and in the vicinity of Fredericksburg, Gillespie County. The extent is roughly 661 square miles. In general the Travis Peak beds consist of conglomerate, composed of coarse rounded pebbles of Ordovician and Carboniferous limestones, granite, schists and quartz derived from adjacent pre-Cambrian and Paleozoic rocks, beds of finely divided cross-bedded pack sand, white siliceous shell breccia resemble the Florida Coquina, and some bands of blue reddish and greenish white clays having the characteristic colors of the Potomac beds of the Atlantic coast and they are sometimes accompanied by lignite and fossil layers.

The thickness of the beds near Travis Peak postoffice in Travis County is 263 ft. while measurements from logs in Bexar County place the thickness at about 480 ft.

Glen Rose Formation

The Glen Rose formation consists mainly of alternating layers of moderately hard and soft rocks. The harder ledges are chiefly limestone which contains no flint. Near the bottom of the formation the limestones are massive but the beds decrease in thickness higher in the section, alternating with clayey or marly layers becoming arenaceous near the top. Some of the limestone layers are fine-grained and quite hard, although as a rule the limestones of this formation are of medium hardness. The marly layers of the formation are usually thin, being from a few inches to one or two feet thick, and rather soft. At the surface the marly layers, like the limestone ledges, are yellow. When buried within the earth they may be at times gray or blue. The formation may usually be recognized by the characteristic succession of hard and soft strata, although, as mentioned above, certain places in the formation are heavily bedded. Occasionally, also the heavy limestone ledges are honey-combed and under these conditions resemble the non-flinty ledges of the overlying Edwards formation.

The Glen Rose formation thickens very rapidly to the southwest. For example, the thickness of this formation is about 300 ft. near Travis Peak postoffice. At Austin its thickness is 575 to 600 ft. In Comal County its thickness is approximately 700 ft., and finally in Bexar County it attains a thickness of about 800 feet. The area of the Glen Rose outcrop, as shown on the accompanying geologic map, is 2489 square miles.

Walnut Clay

The Walnut formation comprises the beds of clays and non-chalky limestones at the base of the Fredericksburg division. They consist of alternations of calcareous laminated clays, weathering yellow on oxidation, semicrystalline limestone flags, and shell agglomerate, all of which grade upward without break through the Comanche Peak into the more chalky beds of the Edwards limestone. In places they weather into rich black soils and make extensive agricultural belts.

The clay varies in thickness from 0 to 40 ft. in this area.

Comanche Peak Limestone and Edwards Limestone

The Walnut beds pass by insensible transition into more calcareous and chalky beds of the upper part of the Fredericksburg division, the lowest beds of which are called Comanche Peak limestone. It occurs above the Walnut Clay and below the first Rudistes beds of the Edwards. It is composed of persistent beds of white, chalky, fossiliferous limestone which varies between 70 and 125 ft. in thickness. The beds are separated by faintly marked planes of stratification, which are generally marked by thin bands.

The Edwards formation, where well developed, shows slight variation in color, composition, texture, and mode of weathering. Most of the beds are as nearly pure carbonate of lime as can be found in nature, but some have admixtures of silica, epsomite, chloride of sodium and other salts. The limestones vary in degree of induration from hard ringing limestone to soft pulverulent chalk that crumbles in the fingers. The beds vary in texture. Some are pervious, while others are close-grained and impervious. Some are homogenous throughout, others have hard and soft spots, the latter dissolving away in the percolation of underground water and producing what is popularly termed "honeycombed" rocks. Flint horizons are very characteristic of the Edwards formation and are definitely known at several places in the formation.

The comanche Peak and Edwards Limestone vary greatly in thickness from 20 ft. on the Red River to about 700 ft. on the Rio Grande. The Comanche Peak is about 65 ft. thick and the Edwards is about 375 ft. at Austin. At San Antonio the Edwards formation is between 400 and 500 ft. thick.

Georgetown Formation

Just above the Edwards is a very hard close-grained rock, containing no flint, known as the Georgetown formation. This and the Edwards formations are important in the San Antonio district as water bearing formations. The thickness of the Georgetown varies from 65 to 80 ft. at Austin to possibly 40 ft. in the Uvalde district.

Del Rio Clay

The Del Rio formation resting on the Georgetown consists largely of clays which on surface exposure are usually yellow, but when encountered below the surface are usually blue in color. The formation contains more or less iron sulphide as pyrite and in well cuttings the amount of pyrite is not infrequently found to be considerable. At San Antonio the thickness is estimated at 50--70 feet. At Austin the thickness varies from 50 to 80 feet.

Buda Formation

The Buda formation is quite uniformly a close-grained, dense, hard limestone. On surface exposures this rock is usually light colored or tinged with gray, yellow or blue. The change of sedimentation from the Del Rio to the overlying Buda appears to have been abrupt, there being little or no gradation between the formations. The thickness varies from 45 ft. at Austin to about 60 ft. at San Antonio.

Eagle Ford Formation

The Eagle Ford formation at Austin consists of calcareous layers with laminated flagstones and bluish or bluish gray clays at the base. In Bexar County the formation is represented chiefly by calcareous and more or less sandy shale. The rock is generally granular in appearance, and breaks horizontally into thin slabs, having a flaggy appearance. The thickness between Austin and San Antonio does not vary to an appreciable extent, being from 30 to 35 ft.

Austin Formation

The Austin formation includes a thick deposit of limestone, chalk and marl. The lower beds of the formations are hard limestones. Above these the formation passes into a more chalky and, as a rule, softer phase, while near the top the deposits become chalky marls. The formation is stratified and consists in places of alternating harder and softer beds which on weathering give a banded appearance, in some instances not entirely unlike that of some exposures of Glen Rose formation. On surface exposures the rocks of this formation are prevailingly creamy yellow, while on freshly broken surfaces the rock is either blue, white or yellow. The formation yields moderate supplies of water, although frequently containing more or less hydrogen sulphide gas.

The thickness of the formation varies greatly and is difficult to determine with any degree of accuracy. At Austin, Hill estimates the thickness at about 400 ft., while well logs from Bexar County show the thickness to be between 300 and 400 feet.

CHAPTER III

PRELIMINARY HYDROLOGICAL CONSIDERATIONS

Capacity of the Various Rock Sheets for Water

Of the numerous beds mentioned above, all those composed of impervious material, such as clays and close textured limestones, may be considered as non-water bearing, and their function in the transmission of water is solely that of control, not of supply, since they retain the water in the water bearing beds. Nearly all of the Cretaceous rock sheets south of the Colorado lying above the Fredericksburg division belong to the category of impervious beds overlying the water-bearing strata. There may be occasionally a few arenaceous layers furnishing a scant supply for dug wells. As a rule, according to those who have endeavored to obtain such wells, the underground water they contain is neither abundant in quantity nor good in quality.

Rocks of open texture, such as sands, conglomerates, and porous, chalky limestones, massive rocks broken by joints, fissures, honeycombs, or other openings, are usually water bearing. Such conditions are mostly found below the Del Rio clay.

It is from these lower beds that one would expect an artesian supply in the region south of the Colorado River. That some of these beds are completely charged with water is demonstrated by observations upon the source of the springs of the plateau region and by the experiments of well drillers.

Summary of the Water Capacities of the Formation of the Cretaceous System

Formation		Permeability	Conductivity
Austin		Fair	Poor
Eagle Ford		Poor	Poor
Buda		Poor	Poor
Del Rio		Poor	Poor
Georgetown		Poor	Poor
Edwards		Poor and Good	Poor and Good
Comanche Peak		Poor and Good	Poor and Good
Walnut Clay		Poor	-
Glen Rose	Upper	Fair	Fair
Glen Rose	Middle	Fair	Poor
Glen Rose	Lower	Fair	Fair
Travis Peak		Good	Good

Structure

a. Regional Dip.

The general direction of the dip of the various Cretaceous formations is coastward or to the southeast, in directions at right angles to the line of outcrop. West of Austin the dip to the southeast is estimated by R. T. Hill to be 13.5 ft. per mile. The dip is about 25 ft. per mile in the region between Marshall Ford and Spicewood Springs, according to measurements made by Prof. F. L. Whitney.

In many places the arrangement of the strata appears to be horizontal but the sheets are all tilted or inclined towards the coast from 10 to 100 ft. per mile. North of the Colorado the beds as a whole have the uniform gently tilted monoclinal arrangement seen on the coastal plain where the rocks dip towards the coast at an angle greater than the surface slope but in the same direction.

South of the Colorado the dip is also coastward, but the angles of inclination are more varied. The rocks of the Edwards Plateau are sometimes almost horizontal with a dip of about 10 ft. per mile, while the strata of the Rio Grande plain are inclined from 50 to 100 ft. per mile. On the plateau the average dip conforms precisely to the average surface slope in many places so that a single formation as the Edwards limestone constitutes nearly the whole surface.

Balcones Fault Zone

The Balcones Fault Zone is probably due to the adjustment by weight of the Cretaceous rocks to the slope of the buried eastern margin of the Wichita paleoplain. The fault zone consists of a number of sub-parallel step faults, all concentrated in a narrow belt of country and attaining a maximum displacement of 1,000 feet. The effect of the numerous faults is to break the regularity of the dip of the strata and to chop them into numerous blocks tilted at various angles within the faulted zone.

The zone is limited nearly everywhere on the west by a larger fault which at Austin has a downthrow of 500 feet. It is in reality a number of short faults overlapping en echelon.

Influence of Central Mineral Region

The presence of the igneous rock core forming the Central Mineral Region is of great importance. The outcrop of the Travis Peak is thus brought very much closer to Austin and the adjacent territory. Without the uplift in Central Mineral Region the Travis Peak sands in that locality would probably be buried and would not outcrop until a point many miles to the north had been reached. But because of this disturbance, the region is flanked on the east by a Travis Peak outcrop. On the southeast the Travis Peak is within 30 miles of Austin and in the Fredericksburg region it is approximately 60 miles from Austin. Thus the edges of the Travis Peak sands are placed within a very reasonable distance of Austin and it is important that they be considered as a catchment area for water feeding the springs of the Balcones fault zone.

Elementary Principal Governing the Occurrence of Underground Water.

Underground water has its origin in rainfall. A part of the rainfall immediately runs off the surface of the ground into the streams and rivers, just as the rain is diverted by the roof from a house into gutters and spouts. Another portion is absorbed temporarily by the surface soil but is again returned to the atmosphere by evaporation either directly or through the agency of vegetation. A third portion penetrates the lower levels of the soil, there to become a part of the great mass of underground water and to help furnish the perennial supply of streams and lakes, of springs and wells and to take part in the geologic work of the most profound importance.

The rocks of the Earth form a system of natural works by which water is collected, stored and distributed. They constitute basins, reservoirs, conduits and other portions of the plant for retaining and distributing underground water. The efficiency of a natural system is determined by the texture of the rocks and the geologic structure of the region so that an understanding of the availibility of the undergroung water in any region necessitates a knowledge of the elementary geology of that region.

By way of summary, the following principles governing the occurrence of underground water are given:

1. The primary source of water is rainfall.
2. Rocks imbibe water by percolation and absorption.
3. Water flows in rocks and the rapidity of flow varies as the capacity for transmission.
4. Different kinds of rocks have different capacities for transmission.
5. Water tends to gravitate downward.
6. Rock sheets drain their water by gravity.

   Gravity drainage may be

   (1) Direct, when the water escapes at the end of a hydrostatic column.

   (2) Artesian, when water escapes at a level higher than the bottom of the hydrostatic column.

CHAPTER IV

FURTHER HYDROLOGICAL CONSIDERATIONS

Catchment Area for Water in Austin-San Antonio Region

Mode of Catchment. Rainfall finds its way into the deeper zones or flows in various ways, either directly by percolation into the exposed ends of strata or indirectly by the seepage from streams and rivers which have cut their valleys through the outcrops. Much of the water is caught directly upon the edges of the Travis Peak and Glen Rose, which outcrop along the western and northern summits and margins of the plateau of the plains, at an elevation higher than that of their embedded continuation along its eastern and southern margin.

No doubt some of the water also enters the basement beds along that portion of the eastern margin of the plateau of the Plains which constitutes the northern border of the Edwards Plateau.

Another large part of the rainfall on the surface of the Edwards Plateau percolates downward through the limestone itself to the water bearing beds. In this manner water often reaches the embed through intricate conduits from the surface such as fissures, caves, and honeycombed spaces in the limestone strata.

Travis Peak Catchment

The area covered by the outcrop of the Travis Peak sands is rather large. From north of Burnet including the drainage of the Colorado River with such smaller tributaries as Bee Creek and Cow Creek, the Pedernales River and its smaller tributaries, the Blanco River, and the Guadalupe River, the sands of the Travis Peak receive their water. By counties the Travis Peak outcrop may be found as follows: Western Travis, Williamson, eastern Burnet, northern Hays, Blanco, Gillespie and other counties along the northern edge of the Edwards Plateau. The outcrop is especially displayed along a line between the town of Burnet and Travis Peak postoffice by Smithwick Mill, along the Colorado Valley between the mouths of Sycamore and Cypress Creeks in Burnet and Travis Counties, respectively, and along the Pedernales River for about 35 miles in Blanco, Hays, and Travis Counties. The effective catchment area of the Trinity sands is about 661 square miles.

Where the Pedernales flows through the outcrop of the arenaceous beds in the above counties, its direction is almost transverse to the direction of the dip and hence it would feed the sands and not be fed by them. In the entire area of the outcrop the sands absorb water like a sponge, one cubic yard of this sand actually absorbing 80 gallons of water. One traveling across the basal Travis Peak outcrop in the Pedernales valley will notice that at certain times of the year the water is fairly swift and deep at one point while just a few miles down stream there will be a dry rock bed with no water in sight. The water has disappeared and gone into the great Travis Peak reservoir which, according to rough estimates, contains 531,300 tons of water.

Glen Rose Formation

The catchment area of the Glen Rose is much larger than that of the Travis Peak, but because of the nature of the material it does not afford nearly so good catchment conditions. The outcrop lies east of the Travis Peak and extends southward in a narrow band from Burnet. The area north of the Colorado is not very large and is bounded on the northeast by the Jollyville plateau, but south of the Colorado there is a broad area extending through Travis, Hays, Blanco, Comal, Kendall, Gillespie, and Bexar Counties. It occupies roughly 2489 square miles.

The sink holes honey-combed and cavernous layers no doubt furnish the conduit for the downward percolation of much surface water. There also exist many impervious alternating clays which stop the water and hold it.

Edwards Formation

This formation outcrops chiefly in the Jollyville plateau region north of Austin, in Kendall and Gillespie Counties and along a strip called the Hardscrabble country which varies from 4 to 15 miles wide and which runs from Austin to San Antonio just east and south of the fault region which lowers it against the Glen Rose formation.

Many interesting caverns of the Edwards Plateau have a great bearing on the distribution of underground water. Although this formation, like the Glen Rose, is not as important as the Travis Peak catchment area, yet the following conditions do have a direct bearing on the water problem.

(1) Small cavities within a stratum; honey-combed structure.

(2) Openings and caverns on bluff faces along streams.

(3) Underground caverns of vast extent.

The area in square miles of this formation is approximately 1229 square miles, the hardscrabble country representing 432 square miles of this number.

Direction of Flow of Water from Catchment Area

Water falling at the outcrops of the above catchment areas or brought by running rivers and creeks enters and becomes available as a source of artesian supply. If the water bearing strata of the catchment area are inclined and are included between overlying and underlying impervious strata, the water will sink until this pervious sheet is entirely saturated, the overlying sheet opposing the tendency of the water to rise through hydrostatic pressure and the impervious stratum beneath preventing escape downward. Water thus enclosed is conducted to a lower level than the outcrop and will remain stored in the earth until an outlet is provided for it.

Water entering the upturned edges of the Travis Peak near Burnet would flow in the pervious layers down the dip. The regional dip of this section is about 25 feet per mile, as determined by Prof. F. L. Whitney. From a detailed study of the geology and topography of the region, the following was deduced:

Taking 300 feet as the thickness of the Glen Rose in the Burnet region, a study of contours shows the top of the Travis Peak to be (1350-300) or 1050 feet above sea level. To the south of this at a point near Volente, Travis County, where the Travis Peak formation dips under the bed of the Colorado River the elevation is 520 feet above sea level. Thus there is a difference of 530 feet in elevation of the catchment beds alone. This shows rather conclusively that, even with a little faulting, there is a strong dip to the south and east.

Barton Springs at Austin is on the downthrow side of the Edwards block which is dropped down on the coastward side of the Balcones fault. The top of the Edwards is found at a point 88 feet above the level of the springs. The elevation of the springs is 450 feet above sea level making the top of the Edwards 538 feet above sea level.

In the northern part of the San Antonio quadrangle (Contour map of U. S. G. S.) just north of the point where the I. & G. N. R. R. crosses Olmos Creek, the structural highs of Austin chalk, which again is on the downthrow side of the fault, are about 800 feet in elevation. According to Dr. Sellards, the thickness of the Austin chalk is 350 feet, that of the Eagle Ford is 32 ft., that of the Buda is 60 ft., and that of the Del Rio is 60 ft., making a total of 502 down to the top of the Georgetown--Edwards. This then makes the top of the Edwards (800—502) or

298 ft. above sea level and 240 ft. lower at San Antonio than at Austin. Even though San Antonio is southwestward of Austin, its southerly direction should make Edwards limestone lower. It is hard to tell how much of this decrease in elevation is due to faulting and how much due to dips but it is safe to say that quite a bit is due to the dip.

Effect of Faulting on Direction of Flow

Faulting causes a discontinuity of strata. When water enters a pervious stratum and continues down the dip to a fault plane, it will do at least one of three things:

(1) It will continue across the fault plane if another pervious layer has been dropped down or pushed up opposite the one which originally carried the water.

(2) It will come up along the fault plane or weakness and in trying to regain its own level will enter a pervious stratum or come to the surface.

(3) It will go down the fault plane until it finds some porous layer.

Faulting often presents a serious problem in determining the direction of flow of water. If an impervious stratum confronts a pervious one on the opposite side of a fault plane, then the natural course will be deflected and the water, in a country where dips are as great as they appear to be in the faulted zone, will naturally come towards the surface. It will probably go into a pervious layer if it should encounter one, but may come to the surface if the hydrostatic pressure is great enough.

The Motion of Underground Waters

In general the water contained in porous soils and rocks is not stationery, but possesses an exceedingly slow although perfectly definite motion. The best evidence of this is supplied by geology which shows that nearly all the rocks have been vastly changed by the work of underground water. Enormous amounts of material have been slowly deposited in the pores of loose sandstone and limestone until they have been converted into strong and nearly impervious rocks. The material had its source in the formation of the numberless cavities elsewhere formed by the opposite process.

The cause of the motion of underground water is the same as the cause of the water movement through the pipes of a water supply plant in a city--the difference is pressure from point to point. The difference in pressure in the case of ground waters is nearly always due to gravity alone, the water flowing from a higher to a lower level.

The rate of the movement of water through a porous soil or rock depends upon several important elements which may be enumerated as follows: (1) the size of the pores of the water bearing medium, the capacity to transmit water being enormously greater for large pores than for small pores; (2) the porosity of the material--flow being much greater for high porosity than for low; (3) the pressure gradient or change in pressure or head per unit length measured in the direction of the motion; (4) the temperature of the water, flow being noticeably greater for high temperature than for low temperature, the flow at 70 degrees F being double that at 32 degrees F.

The height of the water table is constantly subject to variation. Its position at any time is dependent upon the varying relation between rainfall and evaporation. The maps on the accompanying page show this relation.

Another convincing fact about the climate conditions of this area is seen from a study of the above maps on the "Precipitation and Evaporation" in Texas. To have the water in the springs between Austin and San Antonio flowing from the latter vicinity into the Austin region would necessitate the origin of a great amount of this water from the Uvalde district. Now the region around Uvalde is almost semi-arid with its small amount of rainfall. Its rainfall for the past six years ranged from 11 to 38 inches per year, or it received from 7 to 32 inches less per year than Austin. It should be noted that for the six years listed in the table above the average annual rainfall at Austin almost doubles that at Uvalde, the Austin rainfall actually averaging 39 inches, while that at Uvalde averages 21 inches.

It seems impossible that such a country with its low rainfall could furnish Austin or Barton Springs its water, whereas the rainfall of the Austin territory is about 35 inches.

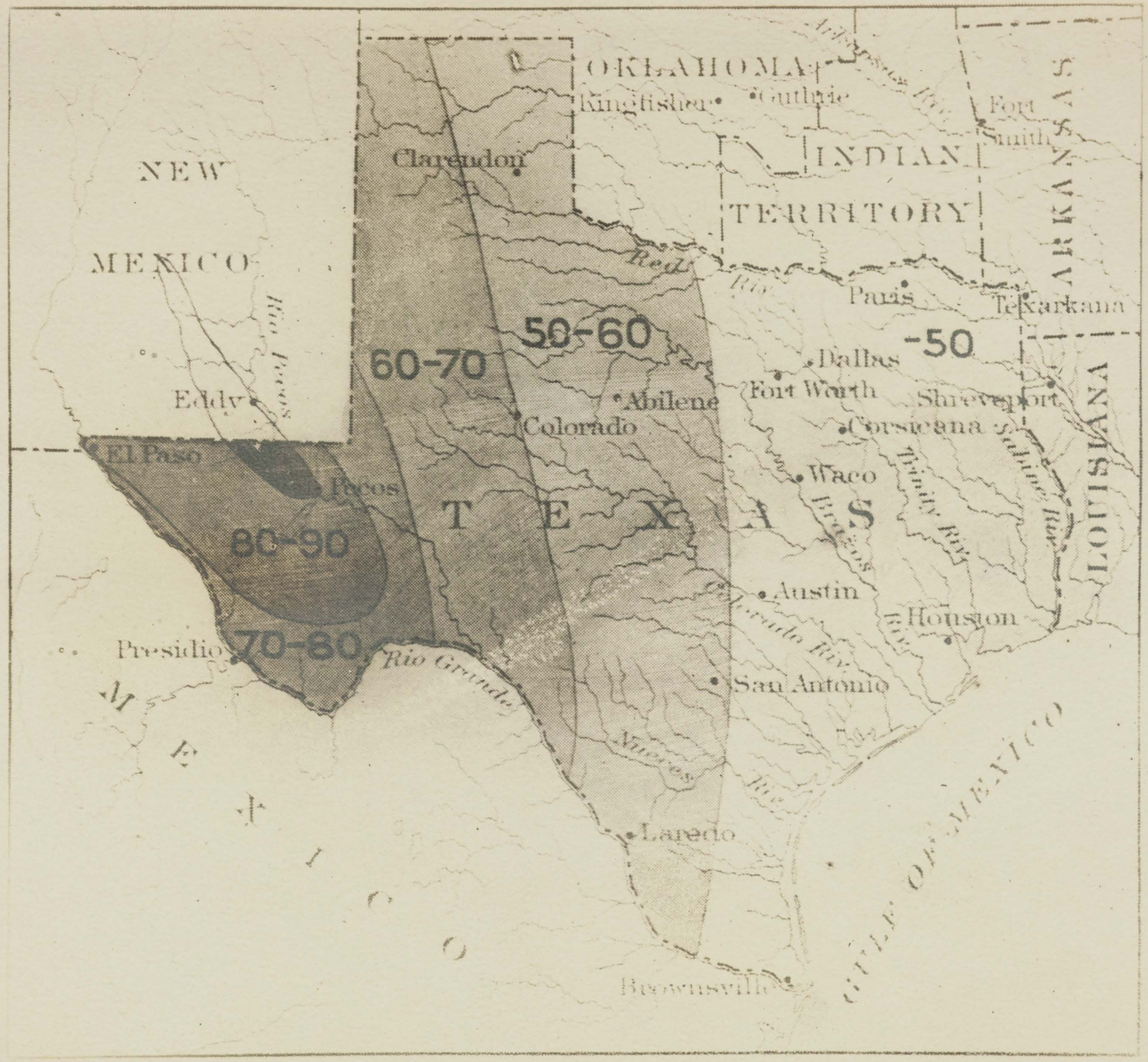
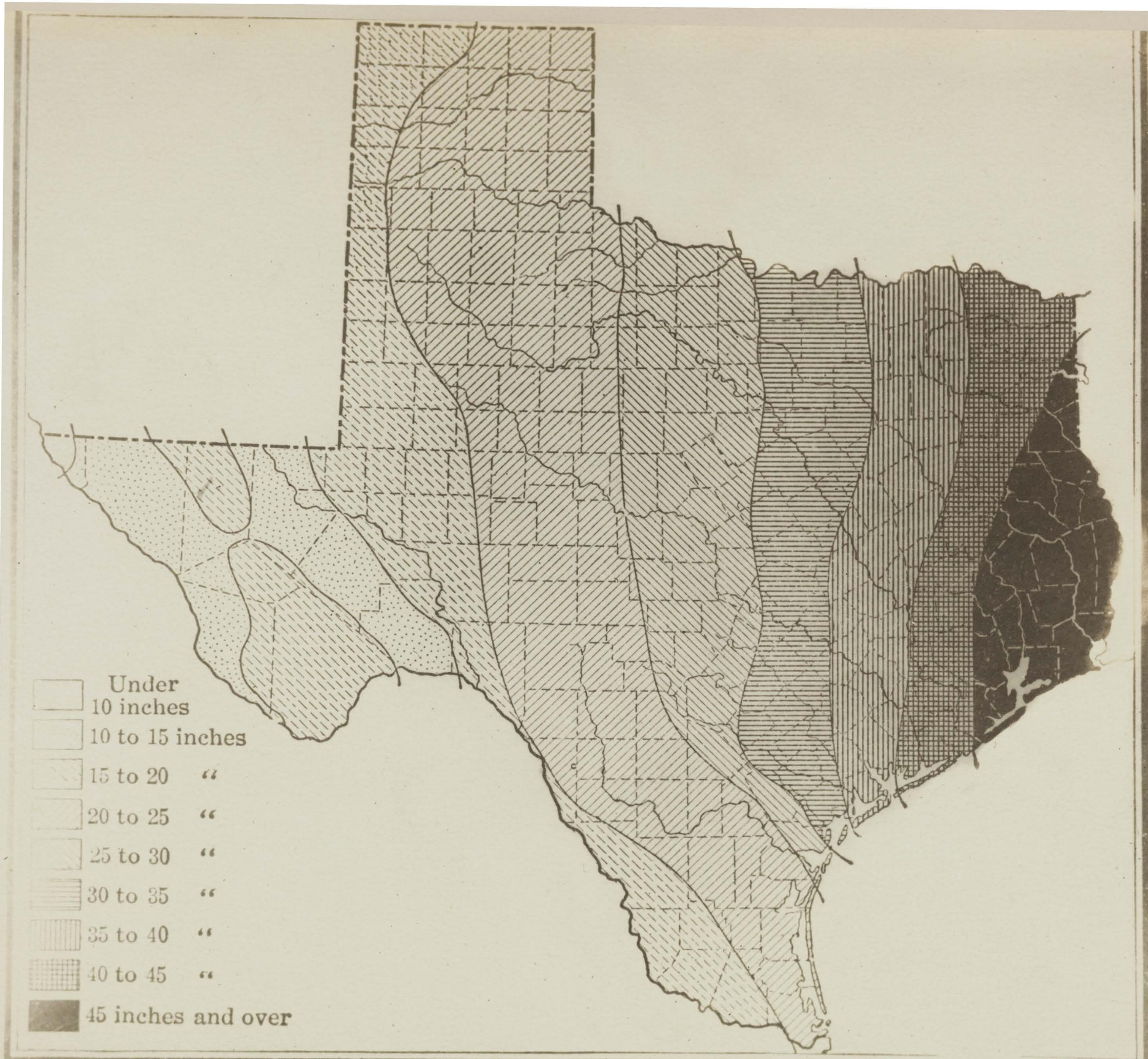
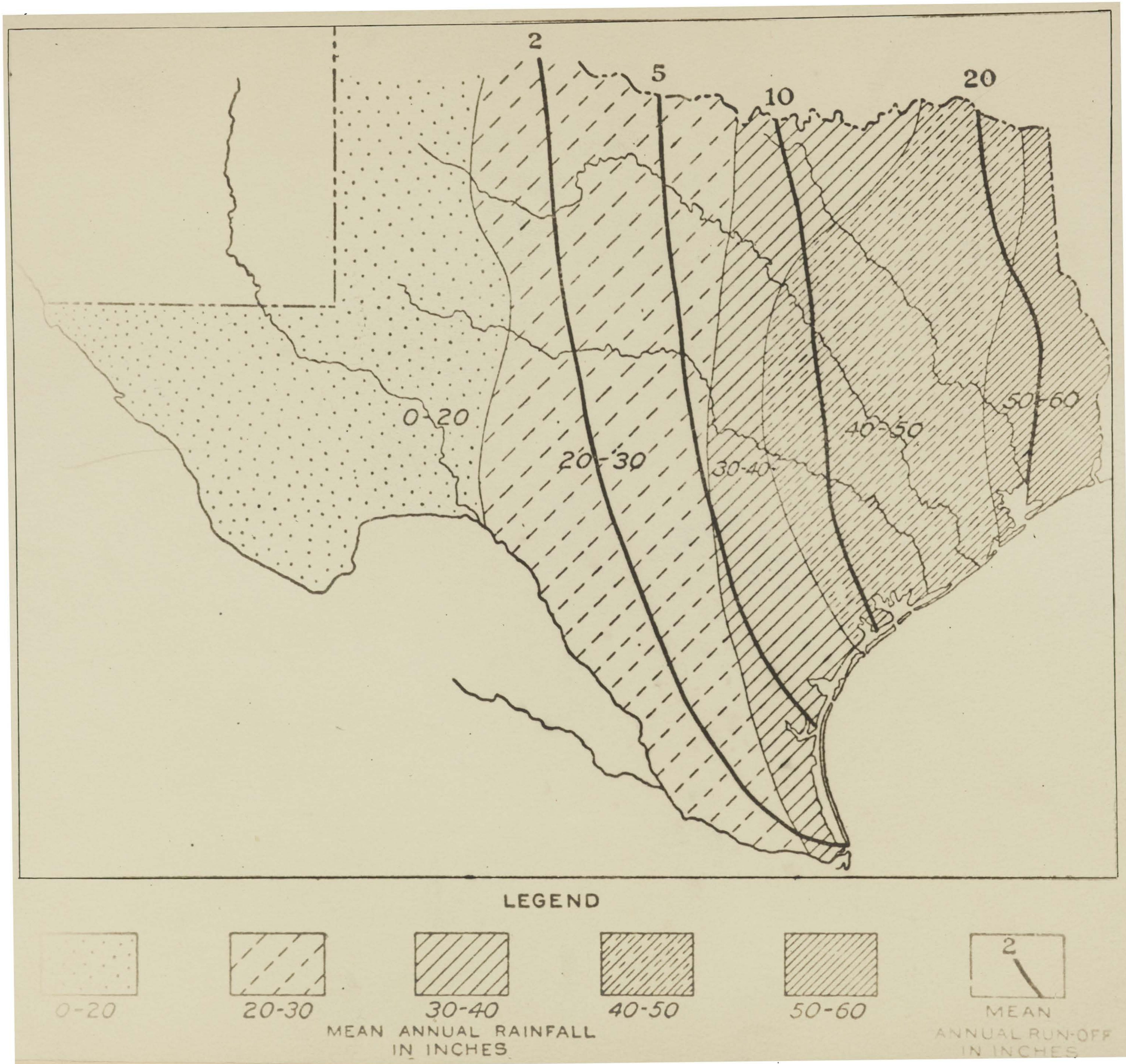


FIG. 16.—EVAPORATION IN THE TEXAS REGION.



Annual Precipitation in Texas Region.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2
MEAN ANNUAL RUN-OFF IN INCHES

Furthermore, the evaporation in the Uvalde--San Antonio district is 50 inches to 60 inches per year, while in the territory around Austin it is less than 50 inches per year as seen from R. T. Hill's maps on "Evaporation".

A very important geological feature to consider is the excessive faulting in the formations between Uvalde and San Antonio. That the surface elevation of the Edwards at Uvalde is greater than that at San Antonio is well known. It is by successive down cross faulting from Uvalde to San Antonio and by general direction of dips that the water would travel in a southeast direction and would not go towards San Antonio.

Granting that the hydrostatic head of water at San Antonio is great enough to force the water up the dip, there are other things to consider. Just as water crosses the fault at San Antonio, so will it have a chance to cross into the coastal plain region through the pervious layers wherever they come in contact with the Hardscrabble block. In fact, there would be a great tendency for the water to do this due to the general south and southwest dip observed by Dr. Sellards in Bexar County (and due to the very steep dips of the coastal plain strata).

In writing of the Hardscrabble country, R. T. Hill points out that, "this district is excessively faulted and jointed and many artesian springs reach the surface." These cross faults would prove a great menace to the flow of water. Numerous evidences of faults are traced, as may be seen from a study of the geologic map, into the Edwards formation in the Hardscrabble country. Because of the nature of the Edwards formation with its similar and massive limestone beds, it is difficult to trace these faults and to tell the amount of faulting. But there is no question that faults actually exist.

Water would have a tendency to come to the surface wherever these faults occur, but it would be water which has as its source the Travis Peak--Glen Rose outcrops of the northwest and not the Edwards of Uvalde--San Antonio region of the southwest. Impervious layers are no doubt dropped down against pervious ones thus blocking the water if it were to come from the latter region. In an area which is so cut up by faulting and in which the water has a tendency to go off in a southerly direction it would be hard to conceive of San Antonio water reaching Austin.

Variations in the barometric pressure produce interesting changes in the position of the water table and still greater changes in the flow of springs and wells. Observations show that the flow of springs and wells increases with a lowering of the barometric pressure.

Chemical Nature of the Underground Water

From the present knowledge of rocks through which wells are drilled, it is known that different strata vary greatly in chemical character. Each bed no doubt contains its peculiar chemical qualities, but in wells penetrating one or more formations, the water from these beds is invariably mixed so that when it reaches the surface it is not representative of any single stratum.

The Austin chalk, miscalled magnesian limestone, contains no magnesia and hence the magnesian content must originate below this formation. It does contain considerable pyrite, however, in quantities sufficient to supply the iron and sulphuretted hydrogen derived from this horizon at San Antonio.

The Eagle Ford shales are somewhat similar to the Austin chalk, so far as accessory minerals are concerned, containing, however, more pyrite and bituminous and lignitic matter.

The Del Rio clays are very impervious and do not affect underground waters seriously unless they percolate through pyritiferous layers, in which case much hydrogen sulphide will be present.

The waters from Georgetown and Upper Edwards are highly impregnated with mineral matters such as sulphur, iron and magnesium sulphate. Waters from the middle and lower Edwards are singularly free from mineral accessories except magnesium and a trace of sodium. This condition harmonizes with the composition of the San Antonio sweet water. The chief ingredients are magnesium and lime--normal material of the Edwards limestone.

Upper Glen Rose beds contain certain strata in which are found deposits bearing strontium, magnesium and sodium.

At the top of the Travis Peak there is another magnesium horizon, but below these beds the sands are very free from any unpleasant ingredient as is attested by the analyses of the waters from certain of the beds. These sands supply the purest, softest and most abundant water of the artesian system.

From various analyses published by Hill, it will be seen that the chief mineral impurities of waters derived from the Edwards beds are chlorides and sulphates of calcium, magnesium and sodium. In this they differ greatly from the potable water of the lower Trinity (Waco) beds in which the chief ingredients are bicarbonates and sulphates of sodium, while the total solids in the former are nearly five times as great as those in the latter.

Numerous springs in the vicinity of Travis Peak and Fredericksburg derive their waters from the Travis Peak sands. There are also numerous surface wells which, with the springs, give up the purest water found in the Comanche series. The quantity and purity of the water increases downward in the series. The water in some of the upper Glen Rose and the Edwards limestones is so strongly impregnated with mineral matter that it is not potable and must be cased off in the wells.

The Glen Rose waters show a larger proportion of solid matter such as salt, magnesia and lime than those of any other reservoir. This solid matter averages 462 grains per gallon, and is seven times as great as in the lower Trinity waters.

The lower Trinity reservoir shows a small proportion of total grains of solids per gallon, a small proportion of salt and an almost entire absence of gypsum and lime, the sodium occuring as sulphates and carbonates. None of the analyses shows any trace of magnesium sulphate; calcium oxide is absent and the water is soft. Calcium sulphate is absent from all of the lower Trinity wells.

The fact that the waters of the fissure springs appear to have the properties of the lower Edwards and Travis Peak artesian waters leads one to accept the hypothesis that the latter waters lie below much of the region in which the fissure springs occur, west of San Antonio, and have not yet been penetrated by the artesian drillings.

A variation is noticeable in all water analyses, which, notwithstanding their imperfections, are sufficient to show that the waters of approximately the same horizon are chemically dissimilar in different localities.

From a study of the chemical relations of the rocks and waters, some useful deductions can be made. Bad waters can and should be cased off wherever encountered and the well continued until a purer flow is struck or the Cretaceous system is entirely passed. This is done in many instances such as the principal wells of San Antonio district. No matter how firm the drill hole, it would pay in all cases to drill wells to the lower waters and case up the well above them in order to insure against the seepage of these mineral waters. In light of the facts given here, it will hardly be excusable hereafter to allow such waters of the upper beds to flow when an intelligent continuation of the well may obtain superior supplies.

Springs from the Above Water-bearing Horizon

It is a significant fact that the trend or line of the great springs along the margin of the plain coincides almost exactly with that of the Balcones fault line. The most conspicuous of these springs are near San Antonio, New Braunfels, San Marcos, Manchaca and Austin. Several groups of springs break out in the vicinity of Austin along the line of secondary faults, accompanying the great fault zone which extends approximately north and south through the east side of Mt. Bonnel. The principal groups are Mormon and Taylor springs, east of the foot of Mt. Bonnel; Sand and Cold spring between the dam and the city; Bee springs and Barton Springs. Sieder's spring on Shoal Creek in the northwest part of the city comes under this group.

Mormon and Taylor springs are covered by the backwater of Lake Austin. Barton Springs occur in Barton Creek about one-quarter mile above its confluence with the Colorado River. Springs on either side of the creek furnish a maximum of about 16,000,000 gallons per day.

The Manchaca springs, about thirteen miles south of Austin on the old San Antonio road, burst from a fissure in the Austin chalk and the run-off finds its way into Onion Creek, The flow is large, but less than that of Barton Springs.

At San Marcos large and beautiful springs break out along the north-south line of bluffs forming the Balcones Escarpment of this region, and from the source of a beautiful river flowing at times 57,000,000 gallons per day. The springs of the Guadalupe and Comal rivers near New Braunfels belong to this class. Those of the Comal have a flow of 200,000,000 gallons per day and are the largest of the whole group. The springs of the San Antonio River just a few miles north of the city, are representative of this type and have attained a flow as high as 27,000,000 gallons per day. The drilling of numerous wells around San Antonio has diminished the flow of the springs to a great extent.

The Balcones fault describes roughly the arc of a circle by its curved path between Austin and San Antonio. This curved path bends out towards the coast or to the southeast in such a way that it suggests a reason for the heavy spring flow at San Marcos and New Braunfels. With these two points lowest on the arc, the water would tend to flow in this direction. The collecting basin should converge between these points. This fact is sustained by the measurements of spring flow which, according to above statements, is small at Austin and San Antonio but increases towards San Marcos and New Braunfels.

A study of the rocks in the vicinity of the springs has shown that they are associated with the system of joints and fractures accompanying the fault line and that their waters ascend to the surface along these fissures. In other words, these waters come from the deep seated rocks and are forced to the surface by hydrostatic pressure.

Although the water travels down the dip, it comes towards the surface at every opportunity, through joints, fissures and cracks trying to seek its own level and rising up from one porous bed to another. Thus the water of the Travis Peak no doubt finds its way up into the pervious layers of the Glen Rose and Edwards limestone. The water around Austin should be high in bicarbonate content and total solids for two reasons:

(1) The area to the north and northwest of Austin is

largely a limestone country. The Jollyville plateau, with its Edwards limestone capping, and the Glen Rose limestones furnish, to a great extent, a catchment area for the water in this immediate vicinity. Numerous caves, sink holes, and porous strata admit water freely. This water, if not charged, will soon become highly charged in the bicarbonate ion. The water is conveyed down the dip through pervious limestone layers and when it reaches Austin it has a high per cent of bicarbonate in its mineral content.

(2) There is also much water coming through the Travis Peak sands which outcrop in the area along the Colorado and around Burnet. This water no doubt has considerable hydrostatic head after entering the sands at an elevation of about 1100 ft. around Burnet, the water travels down the dip in the general direction of Austin. The dip must be rather steep because the sands dip under the Colorado River at Volente, some eighteen miles distant at 520 ft. above sea level. In the Spicewood Springs well, which is twelve miles southeast of this point, the top of the sands are encountered at 145 ft. above sea level (Surface 750 ft.—30 ft. to top of Glen Rose--575 ft. to top of Travis Peak). The dip of the Travis Peak sands is about 25 ft. per mile as observed by Prof. F. L. Whitney. The water continues on its down dip migration until it reaches some point or fault plane through which it can again seek its own level. The first plane of any consequence is the fault which marks the west side of the Hardscrabble country where the Edwards formation has been dropped down against the Glen Rose. This fault passes along the southeast end of Mt.

Bonnel and continues on through Oak Hill. When the water reaches this plane some of it comes up until it strikes the pervious layers of the Edwards limestone. It travels through these layers dissolving the limestone as it goes. It, no doubt, becomes polluted by surface drains of the Hardscrabble country and finally comes to the surface at such places as Barton Springs. At this point, the country is traversed by a cross-fault of 88 ft. throw, and the water has been through about eight or nine miles of limestone before it reaches the springs.

The water of the Travis Peak outcrops along the Pedernales and in the Blanco-Fredericksburg area would not come to Austin but travel with the dip in a more southerly direction towards San Marcos, New Braunfels and San Antonio. Since it enters directly into the Trinity sands its mineral content and especially its bicarbonate content should be lower to the southwest of Barton Springs.

From the similarity of color, taste and temperature of this chain of springs and from their association with the Balcones scarp and faults, there can be no doubt that they are of similar nature and origin.

The temperature of the Comal Springs is 72 degrees F, that of San Marcos springs is 71 degrees F, and that of Barton Springs is 70½ degrees F. This water, as explained, with a temperature so near the mean annual surface temperature cannot come from a very deep source. Considering, as stated above, that the Austin water comes largely from the limestone country on the north and partly from the catchment area of the lower formations, but that most of the water is from the latter, one might explain the temperature difference by the following:

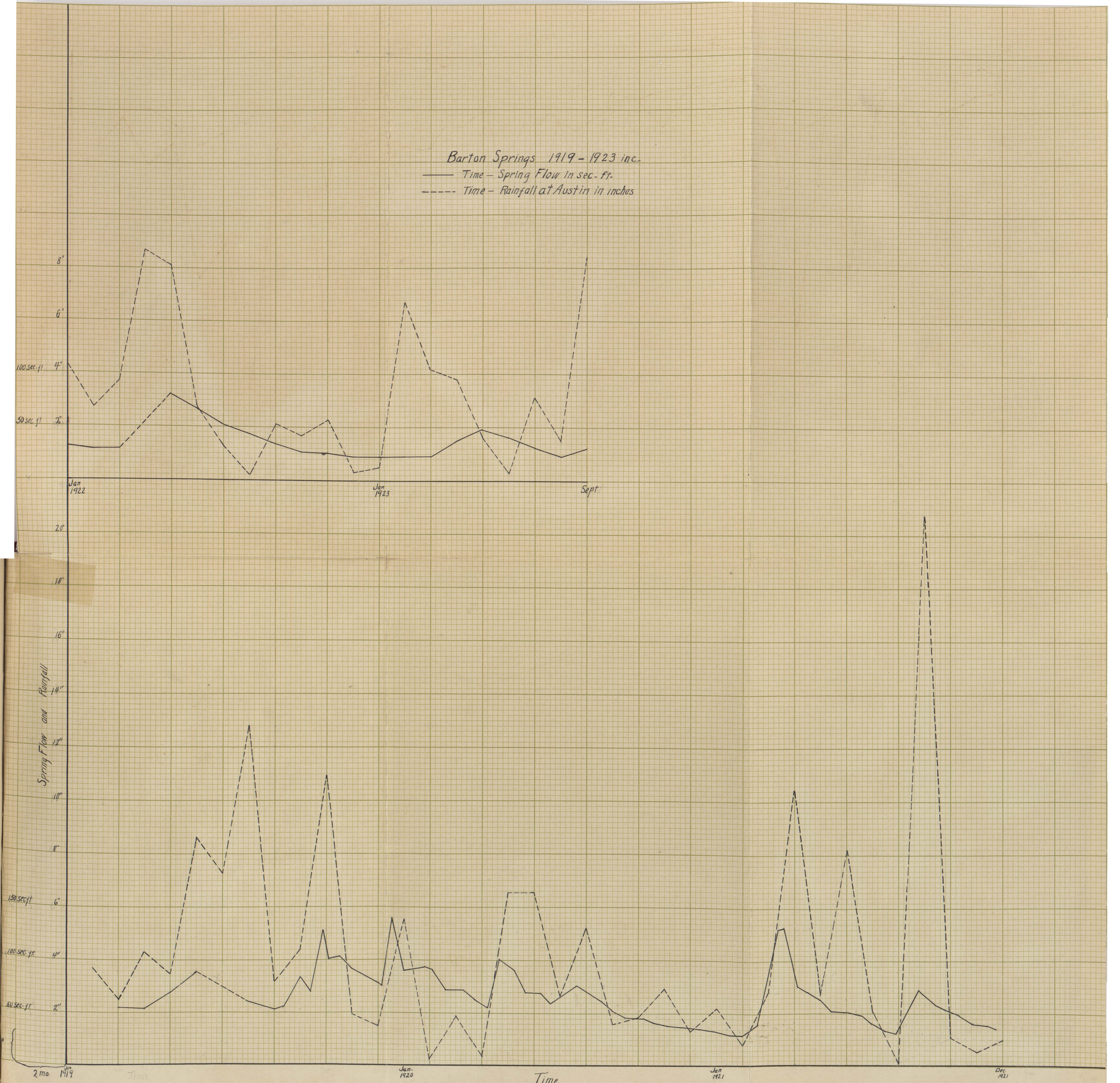
The Travis Peak formation transmits water more freely and through a much shorter distance than does the limestone country to the north of Austin. Hence its temperature from the warm river water is not greatly changed and it would warm the Edwards waters more and more towards San Antonio.

The temperature of the water brought by these springs from their subterrenean sources is 69 degrees to 72 degrees F and does not differ very much from the mean annual temperature of the air of Texas. As the normal downward temperature change requires only 50 or 60 ft. of depth for one degree of temperature change, the formation cannot be many hundred feet below the surface. Their great volume shows that their chief source is a formation which transmits water freely. Their freedom from hydrogen sulphide and other ingredients that would be detected by taste or smell excludes from consideration the higher water horizons of the Edwards limestone. The various facts leave no reasonable doubt that their water is derived from either the "sweet water" horizon of the Edwards formation or the Travis Peak sands; that is they have the same source as the purer waters of the artesian wells.

The fact that the flow from the various springs is slow in showing sympathetic variation with drought or rainfall is evidence that the reservoir supplying them is of vast extent.

The above statement does not intend to convey the idea that a rainfall does not affect spring flow, but from the chart it will be seen that the flow of Barton Springs is fairly constant. That surface water just after rains affects the spring flow is clearly indicated. But that the flow of the spring is slow in following the curve showing rainfall either up or down and the fact that the spring flow curve is confined within fairly narrow limits does show that there is a reliable source--a vast reservoir for a large amount of the water.

The map on the accompanying page, showing the "Run-off", should be compared with rainfall and spring flow as plotted by the curve.


Barton Springs 1919 - 1923 inc.
Time - Spring Flow in sec.-ft.
Time - Rainfall at Austin in inches
8"
6"
100 sec. ft 4"
50 sec. ft 2"
Jan 1922
Jan 1923
Sept
20"
18"
16"
14"
12"
10"
8"
Spring Flow and Rainfall
150 sec ft 6"
100 sec. ft. 4"
50 sec. ft 2"
2 mo.
Jan 1919
Jan 1920
Time
Jan 1921
Dec 1921

All of Travis County is underlain by Trinity reservoirs which outcrop, as the Travis Peak beds at the extreme western edge of the county, and which are struck in the wells at Austin at depths of from 1500 ft. to 2000 ft. below the surface.

East of the Balcones fault line the Fredericksburg reservoir is also embedded and its waters are reached at Austin at a depth of 420 ft.

The artesian reservoirs and conditions of availabilities are entirely different in the Edwards Cut Plain, Hardscrabble and Black Prairie districts. In the former only Trinity reservoirs are available, but it is hardly probable that flowing water can be obtained except in the immediate valley of the Colorado Canyon below an altitude of 650 ft. In the Hardscrabble district the Fredericksburg reservoirs are embedded and available as well as the Trinity reservoirs. Many springs reach the surface through joints and faults of the district.

In the Black Prairie district the Fredericksburg and Trinity reservoirs are deeply imbedded and the area in which deep flowing wells can be obtained is extensive, practically including all points below 630 feet.

All other wells are incomplete since they have not reached the best water of the district--the lower Travis Peak reservoir.

In general the classification of the water conditions for the county holds for that of the City of Austin itself.

There are three important water-bearing horizons in the Comanchean beneath Austin.

1. Capitol well, charged with sulphur and injurious mineral ingredients. Water undoubtedly obtained in the Edwards beds, 90 to 140 ft. below the Del Rio clay.

2. The next flow is one thousand feet lower in the series in the transition beds between the Glen Rose and Travis Peak formation. It is the uppermost of the water bearing strata characterizing the base of the Cretaceous.

3. One hundred and sixty feet below this is the Asylum well, which taps the lowest of the water-bearing beds in the basement or Travis Peak sands. These produce the purest water. The Insane Asylum well, the St. Edwards well, the Natatorium well flowing 200,000 gallons per day, and the Groom Well have penetrated the basement sands.

The above classification deals only with the water-bearing horizons on the downthrow side of the fault. There are two other important water-bearing areas in the vicinity of Austin which should be considered. One is the Edwards beds beneath the Hardscrabble country to the south of the river. The other area is that country on the upthrow side of the fault, which is underlain by the Edwards, Glen Rose and Travis Peak water-bearing strata.

Wells in the country between Oak Hill and Manchaca furnish examples of the former, while the Spicewood well is located in the latter territory.

The water in the Hardscrabble country is found at a depth of 200 to 300 feet below the surface, and this is indicated by the low temperature of the water which is 69 degrees F at New Braunfels, 70 degrees F at San Marcos and 71 degrees F at Barton Springs--a temperature which corresponds to a depth of 250 ft. below the surface.

The width of the Hardscrabble country is shown on the accompanying map. It has been found that good water may be obtained in abundance in this belt, while just across the two fault lines limiting this belt, this water is not obtained at similar depths. Mr. W. W. Gorroh, on the Manchaca-Oak Hill road about one and one-half miles from the Colorado River, struck salt water at 300 ft. while one-fourth of a mile further west Mr. Fred Fitch and Mr. Frank Cullen obtained good water at 281 ft. The last two wells are between the fault lines. On the road to Oak Hill there are wells which supply good water identical in composition with the Barton Springs water.

This water, as has been explained above, is no doubt found in the Edwards limestone. It has as its catchment source the sands of Travis Peak which outcrop in the north and northwestern part of the country and the outcrop of the Edwards limestone to the north and northeast in the Jollyville plateau country. In the first case the water travels down the dip through the Travis Peak and comes up through the fault to the porous layers of the Edwards where it increases in lime content as it flows through the limestone. In the second case the water comes directly from the

Edwards outcrop down the dip through the porous layers until it finds its way to the surface by springs or wells.

The water from the Travis Peak reservoir has as its source the outcrop of the Travis Peak sands to the north and northwest. It travels down the dip through the porous Travis Peak sands and furnishes the purest supply of water that can be reached by the drill around Austin. It is the opinion of the writer that this reservoir is the most potential one within the reach of the drill. Because of the very porous nature of the sands and because they are amply fed by surface outcrop and stream flow, a driller should not stop until this water bearing horizon has been reached.

The well at Spicewood Springs, drilled by the City of Austin, furnishes some excellent data for study. The elevation of the water in the well is 30 feet below the elevation of the City reservoir.

Dr. Schoch's report gives the following data for the Spicewood Springs well:

> "The Spicewood Springs well struck the first large flow of water--which could not be bailed down--at 950 to 960 feet. At first it rose merely to the 100 foot level because there was a hole in the casing. After this hole was repaired the water rose within 60 ft. of the top. When drilling was suspended, the coarse basal sands of the Travis Peak formation had not been reached."

The following analysis of the water found at 950 ft. or the upper Travis Peak sands is furnished by Dr. Schoch: (The figures express parts of soluble salt constituents per million parts of water).

Total Solids	600 p. p. M
Silicia	little
Alumina & Iron Oxide	little
Calcium ion	10.2
Magnesium ion	33.9
Sodium ion	129.9
Carbonic ion	14.8
Bicarbonate ion	76.8
Chloride ion	138.6
Sulphate ion	159.7

The analysis shows that the water is good drinking water.

Dr. Schoch adds:

> "The upper sands of this reservoir contain a water of fair quality which rises to a height of about 690 feet elevation above sea level--or about 190 feet higher than the ground on Sixth Street or 30 ft. lower than the surface at the City Water Reservoir. The readiness with which the water rises in the well when first struck, and the persistence of the level in spite of vigorous bailing, indicates that a relatively large amount of water can be secured from these wells. From a sanitary standpoint this water is likely to be--and to remain--extremely pure."

It is an established fact that under normal conditions the deeper the drill goes into the Travis Peak, the better the water encountered.

Because of the depth to good Travis Peak water (St. Edwards College Well, 2053 ft., State Insane Asylum, 1935 ft.) and on account of poor water found at certain horizons above the good water, the wells on the downthrow side of the fault would be excluded by the writer as a reliable source of good pure water when it is at all practicable to reach the Travis Peak reservoir on the upthrow side. This reservoir should be favored even to the Hardscrabble wells, because the purity and the potential supply of the Travis Peak, in the opinion of the author, cannot be questioned.

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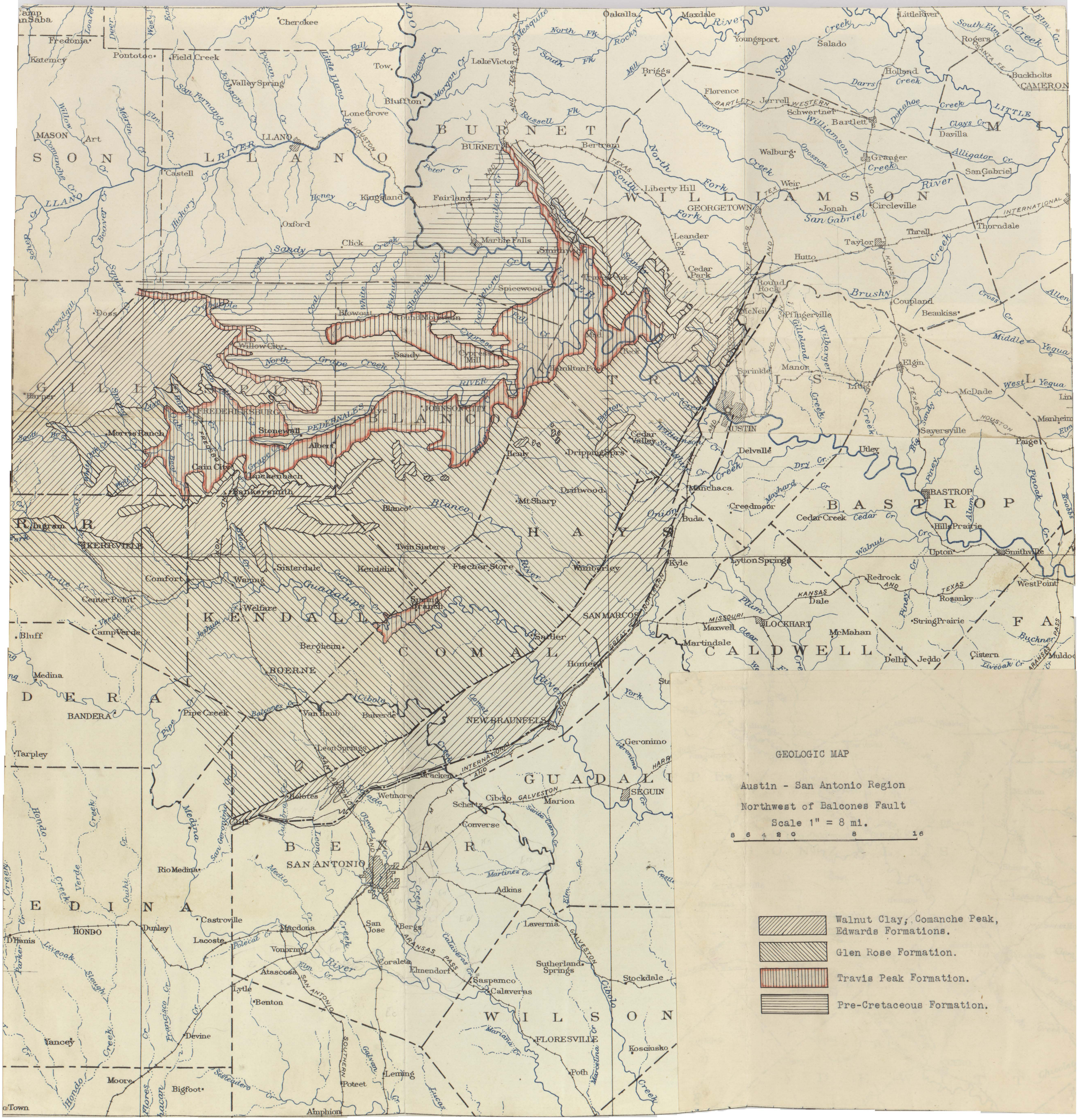
GEOLOGIC MAP
Austin - San Antonio Region
Northwest of Balcones Fault
Scale 1" = 8 mi.
8 6 4 2 0 8 16
Walnut Clay, Comanche Peak, Edwards Formations.
Glen Rose Formation.
Travis Peak Formation.
Pre-Cretaceous Formation.
BURNET
LLANO
WILLIAMSON
TRAVIS
BLANCO
HAYS
KENDALL
COMAL
BEXAR
BASTROP
CALDWELL
GUADALUPE
WILSON
AUSTIN
SAN ANTONIO
SAN MARCOS
NEW BRAUNFELS
FREDERICKSBURG
GEORGETOWN
BOERNE